SPACE STRUCTURES TECHNOLOGY FOR FUTURE FLIGHT SYSTEMS

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ABSTRACT:

Since the early 1990s, NASA has focused on adapting the Faster, Better, and Cheaper (FBC) approach to develop space missions. Simply speaking, FBC is to improve performance by being more efficient and innovative. One of the key requirements for successful FBC implementation is the rapid development and timely infusion of advanced technologies. In meeting this requirement, the past decade has seen an exceptionally high level of research efforts by NASA and its industry and academic partners on developing breakthrough space technologies, including space structures.

Space structures technology compasses a wide range of component technologies. It consists of not only the core methodologies of structural design, analysis, fabrication, assembly, and test verification, but also many peripheral technologies, such as materials selection, characterization and application, thermal control and management, mechanisms, meteoroid and radiation protection, electronic packaging and mounting, and structures/control interactions. In the early years of space age, i.e., the time period extending from the late 1950s through the 1960s, advance of space systems was mainly led and paced by the development of structural systems that can survive severe vibro-acoustic loads imposed by launch, as well as the yet-to-be-explored space environments. In the 1970s, the maturing of advanced computational methods, such as the finite-element modeling method, and the wide application of computers were largely responsible for improved performance and reliability of complicated space structural systems. Figure 1 shows the Voyager I, which is one of the spacecraft launched in that period. In the 1980s, graphite/epoxy and other composites started to join aluminum alloys and titanium alloys to be a workhorse material for space structures. Many lightweight composite structural components were used in large space systems flown in the 19080s and the early 1990s. These included the Space Shuttle and several JPL-developed large spacecraft, such as the Galileo, Magellan, and Ulysses. These large spacecraft were developed for space exploration missions with extremely ambitious science objectives. Each spacecraft weighed several thousands of kilograms and was equipped with a large numbers of science instruments. It was also in the late 1980s that smart structures started to be used in a new generation of space mechanisms, vibration control devices, and health-monitoring systems.

The launch of the 5,655-kg Cassini (see Figure 2) in 1997 signaled the end of the age of large spacecraft. Due preliminarily to the tight space budgets, a major paradigm shift occurred around 1990. It is now believed that the same amount or even more science returns can be obtained by flying more frequent missions with small spacecraft, including micro-spacecraft and nano-spacecraft, that has only a few instruments on-board. A large spacecraft of the Galileo-class can take up to a decade and multiple billions of dollars to develop. A small spacecraft, on the other hand, can be developed in less than two years and costs only a fraction of that required for a large spacecraft. Most of the NASA space science missions planned for the next two decades will be carried out by small spacecraft. Figure 3 shows the Deep Space 1 (DS-1), which is a small spacecraft recently flown on a technology validation mission. Figure 4 presents one of the many conceptual micro-spacecraft designs currently being studied.

To support the FBC development of small spacecraft, intensive research efforts aimed at improving cost efficiency of structural development have been initiated. In the past few years, many new and improved structural design, analysis, fabrication, and test methodologies have been proposed and/or implemented. This has led to significant reductions in development time and life cycle cost. More importantly, due to focused development and rapid infusion of breakthrough technologies, structural systems are becoming smaller, lighter, and yet more capable. The space structures technologies that have received much attention include: space inflatable and rigidizable structures, multifunctional structures and films, nanotube materials, super-lightweight pressure vessels, and a new generation of smart structures and materials. For example, Figure 5 shows an engineering model of the JPL-developed inflatable synthetic-aperture-radar array antenna. This fully functional radar antenna has an multi-layer aperture of 3 m x 1 m. The total weight of the antenna is only 16 kilograms, which include the weight of a self-contained inflation system used for deployment. The launch volume of the stowed antenna is less than 0.25 cubic meters. Figure 6 shows multifunctional structures (MFS) experiment developed and flown on the DS-1 for technology validation. Compared to the conventional design of comparable performance, this cableless MFS system has achieved order-of-magnitude mass and volume reductions by integrating the functions of structural support and protection, thermal management, electronic packaging, flex circuitry, and flex interconnect for data transmission and power distribution.

This paper reviews recent advances of space structures technologies. Future development and applications of several emerging technologies, including inflatable/rigidizable structures and multifunctional structures, will also be discussed.

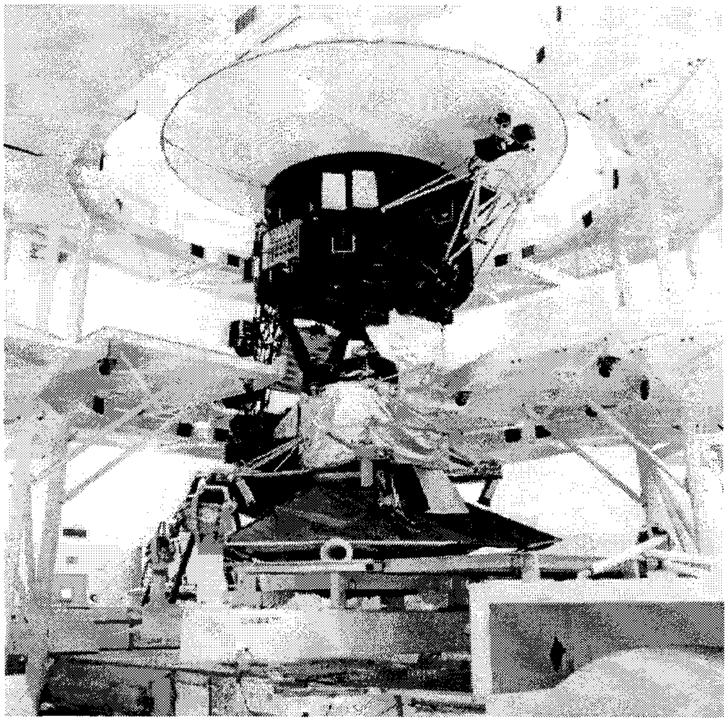

Figure 1. Thermal-Vac Testing of the Voyager I

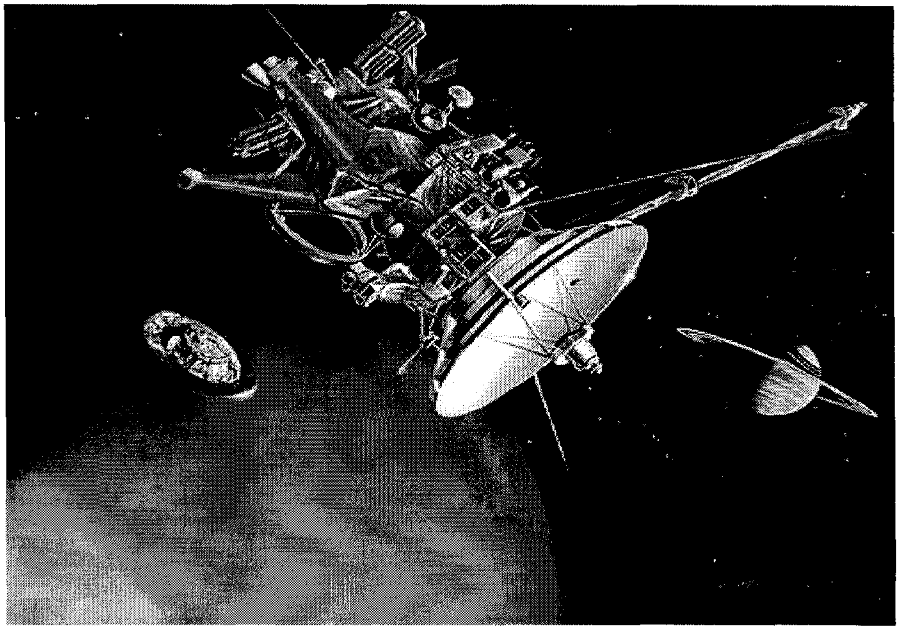

Figure 2. Artist Illustration of the Cassini at Saturn

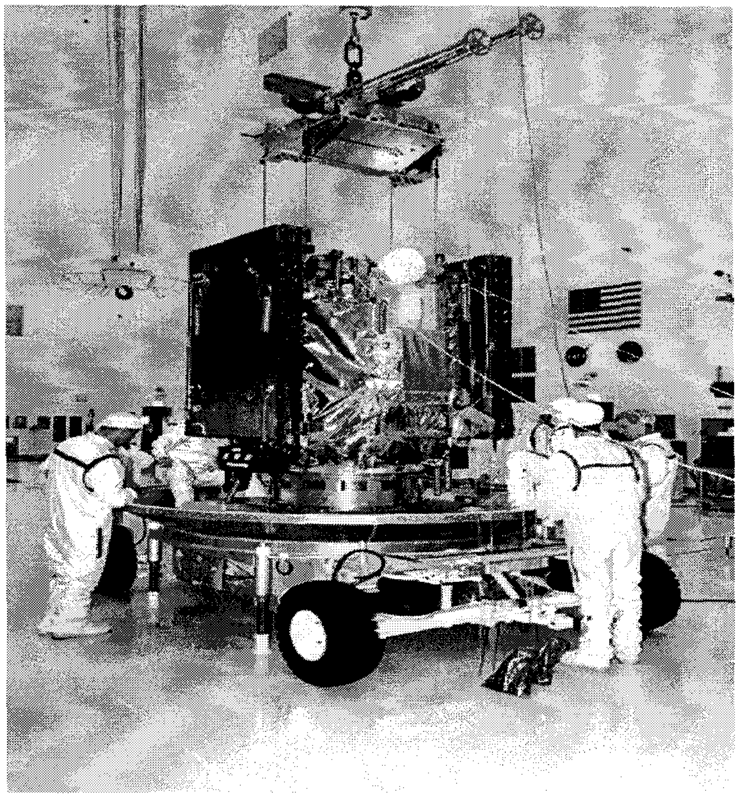

Figure 3. Deep Space One (DS-1) Spacecraft

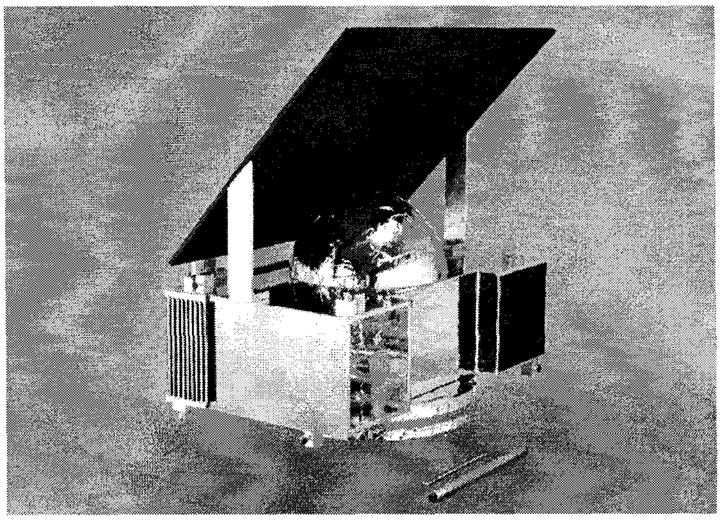

Figure 4. A Micro-Spacecraft Design Concept

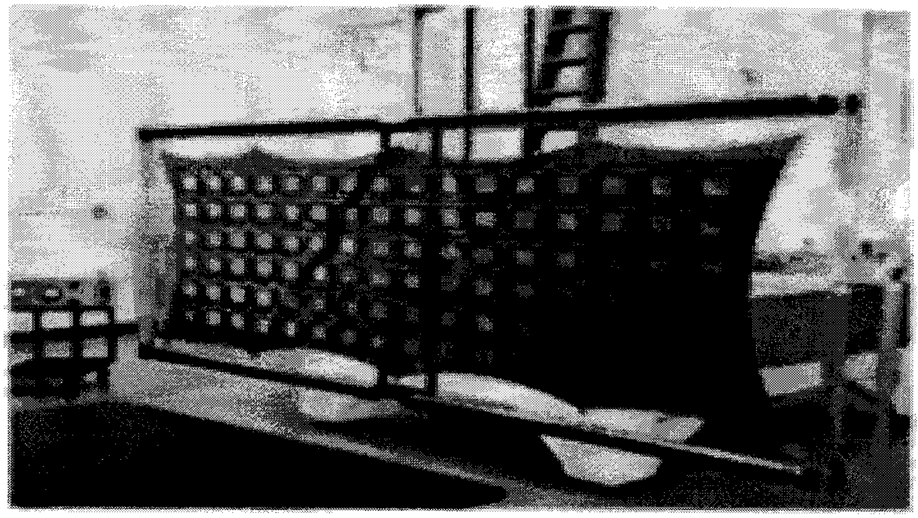

Figure 5. Engineering Model of the Inflatable SAR Antenna

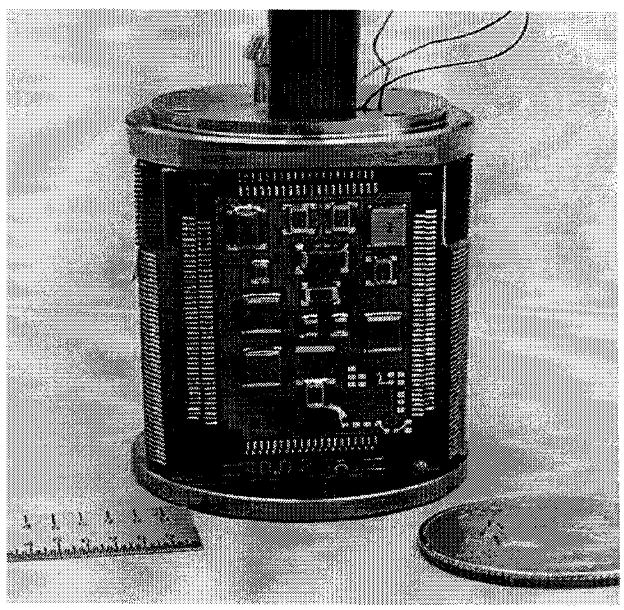

Figure 6. The DS-1 MFS Experiment